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(54) Beam splitter

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PATENT SPECIFICATION

1. TITLE OF INVENTION
Beam splitter
2. CLAIM

(1) In beam splitter wherein incident light enters at incident point of one of the side surfaces of transparent substrate having a pair of mutually parallel side surfaces, one of reflective film or semi-transmitting film is located on other side of said side surface and one side of said side surface (except for the region of said light incident point), respectively, to repeats internal reflection and exiting light is split into two or more of light beam out of said semi-transmitting film; beam splitter which is characterized that optical film thickness of said semi-transmitting film is continuously reduced or increased along longitudinal direction of said side surfaces.

3. DETAILED DESCRIPTION OF THE INVENTION

This invention concerns beam splitter which splits light.

Previously, as this type of beam splitter, there have been known, (1) those which obtain necessary quantity of parallel beams by combining several optical components such as total reflection mirrors or semi-transmitting mirrors, and (2) those which is located with a reflective film on one side of side surface of transparent substrate having a pair of mutually parallel side surfaces, and located with semi-transmitting films having mutually different film properties being separated into number zones corresponding to the number of

split so that intensity of exiting light being split into two or more will be mutually equal on the other side surface, as introduced in US Patent 4,125,846.

However, the beam splitter of item (1) had problems such as that it is large in apparatus and not only the production cost is expensive but also improvement of accuracy of shape of exiting split light and mutual parallelism are difficult. Also, the beam splitter of item (2) had limitations that not only the production is difficult and expensive because semi-transparent films in different film properties each other are located in different zones, but also it is essential use substantially narrower beam compared to the spacing of each zone so that exiting light will not cross the border of adjacent films of each zone, and to accurately adjust incident position and incident angle of light.

The objective of this invention is to eliminate above described problems, which means that firstly to provide beam splitters which are easy to produce and easy to adjust in use, secondary to provide beam splitters with reduced production cost, and thirdly to provide beam splitters which well maintain properties and shape of exiting split light.

This invention accomplishes above described objectives by locating a reflective film on one side of opposing and mutually parallel side surfaces of transparent substrate and semi-transparent film on the other side, and by continuously decreasing or increasing optical film thickness of said semi-transparent film, along longitudinal direction of other side, without having discontinuous boundaries between each split existing light at all.

At first, optical principle of the semi-transmitting film which is the feature of this invention is explained, in order to make understanding of this invention easier. In the case where a semi-transmission film comprises multi-layer film wherein high refractive index substance and low refractive index substance of dielectric which have little light absorption are alternatively laminated, when optical thickness (product of refractive index and geometric film thickness, the same hereafter) of each layer decreases from $\lambda_1/4$ to $\lambda_2/4$, $\lambda_3/4$ ..., which means that center wave length of transmission property reduces from λ_1 to λ_2, λ_3 ..., light transmittance at certain wave length λ_0 which is greater than the wave length λ_1 gradually increases as $T_1 \rightarrow T_2 \rightarrow T_3$ along with the decrease of optical film thickness $\lambda_1/4 \rightarrow \lambda_2/4 \rightarrow \lambda_3/4$ as shown in Figure 1.

Therefore as shown in Figure 2, light transmittance T_1, T_2 and T_3 of center wave length λ_1, λ_2 and λ_3 may be realized with single dielectric multi-layer film 5, by laminating dielectric multi-layer film 5 on a light transmitting substrate 4, and continuously reducing optical film thickness of each layer of it at light passage 1, 2 and 3 as $\lambda_1/4$, $\lambda_2/4$ and $\lambda_3/4$, respectively.

This invention was invented based on above described optical principle, and in the following, embodiments of this invention are described in detail by referring to drawings.

Figure 3 (a) and (b) are schematic drawings showing an embodiment example of this invention when incident light is split into five parallel exiting light.

The light transmitting substrate 6 comprises optical glass of which glass type is BSC-7 (product name of Hoya Glass Co., Ltd.), has a pair of side surfaces 7 and 8 which are mutually parallel in longitudinal direction, and these side surfaces 7 and 8 are formed into smooth planes. Anti-reflective film 11 comprising two layers of magnesium fluoride (MgF_2, refractive index n = 1.38) and zirconium oxide (ZrO_2, n = 2.0) is located at incident point 10 of incident light 9 on the side surface 7, reflective film 12 comprising dielectric multi-layer film which is alternatively laminated with titanium dioxide (TiO2, n = 2.3) and silicon dioxide (SiO2, n = 1.46) up to 21 layers is located other region of the side surface 7 except for this anti-reflective film 11, and each of reflection points 13 through 17 is positioned on this reflective film 12 to form light passage of total reflection. Next on the side surface 8, semi-transmitting film 23 comprising dielectric multi-layer film which is designed

that intensity of five split exiting light 18 to 22 are mutually equal and usage efficiency of light is as high as possible. Which means that this semi-transmitting film 23 is dielectric multi-layer film which is 9 layers of alternative lamination of titanium dioxide (n = 2.3) which is in relatively high refractive index and magnesium fluoride (n = 1.38) which is in relatively low refractive index, and it is in a film structure that optical film thickness of each layer continuously decreases from the light exiting point 24 to 28 as shown in Figure 4. Where, optical film thickness in Figure 4 is shown in relative value, however, as absolute value, it is 130.5 nm at the light exiting point 24 for 632.8 nm light beam. This continuously decreasing film may be formed by applying vapor coating while placing the side surface 8 of substrate 6 in right angle against flying direction of evaporated substance, then tilting in specific angle, 30° for example, with the light exiting point 24 as the center, if it is vapor coated.

Unnecessary beams of sixth and beyond may be eliminated by coating a light absorbing film 29 on the side surface 8, for example.

According to above construction, transmittance and amount of exiting light concerning five exiting light in this example are as shown in Table 1 and amount of each exiting light is distributed within 0.160 I to 0.191 I, and 80 % of light is able to be effectively used compared to ideal value of 0.2 I, even with the minimum 0.160 I. Where, I is amount of incident light.

Table 1

Exiting light	Transmittance (%)	Amount of exiting light
18	16.0	0.160 I
19	21.5	0.181 I
20	29.0	0.191 I
21	40.5	0.190 I
22	57.5	0.160 I

Further, because there is no boundary between exiting beam each other, shape of light beam will not be deformed at use, and such as distance adjustment of its exiting beam may be done very easily. Especially when the ratio of beam diameter and beam distance is close to 1, previous method was easily affected by boundaries, however, according to this invention, there is an advantage that it is not affected by them at all.

The accuracy concerning the parallelism of exiting light is determined by the parallelism of side surfaces 7 and 8 of light transmitting substrate 6 which is optically polished, and high accuracy is able to be obtained according to finishing accuracy of grinding. Further, because dielectric materials having almost no light absorption are used in multi-layer film as the reflective film 12 and semi-transmission film 23, it is able to effectively utilize entire amount of light.

The multi-layer dielectric film may be easily laminated by using a widely used vapor coating unit for producing optical thin film. Especially the semi-transmitting film 23 which is the characteristic of this invention is able to reduce production cost because it is able to take a process to alternatively and continuously laminate titanium dioxide and magnesium fluoride with single vacuum exhaust process after setting the transparent substrate 6 in a vapor coating init.

In the embodiment example which is shown in Figure 3, a case of semi-transmitting film 23 on the side surface 8 is mentioned wherein it continuously decreases from the light exiting points 24 to 28, however, similar optical property is obtained in a case wherein the film thickness continuously increases, instead. In this case, optical thickness against light exiting points is shown in Figure 5 and transmittance and amount of exiting light of each exiting light are shown in Table 2. Where, the semi-transmitting film of this case comprises alternating 10 layers of film of titanium dioxide and magnesium fluoride, and absolute value of optical film thickness at the light exiting point 24 was set at 185.1 nm for light beam of 632.8 nm.

Table 2

Exiting light	Transmittance (%)	Amount of exiting light
18	16.5	0.165 I
19	22.5	0.188 I
20	32.0	0.207 I
21	46.5	0.205 I
22	69.0	0.162 I

Although incident light 9 and exiting light 18 through 22 are in mutually the same direction in the embodiment example being shown in Figure 3, the exiting light 18 through 22 may be taken out from each of light exiting points 24 to 28 of the semi transmitting film 23 in opposite direction from the incident light 9, by entering the incident light 9 into the semi-transmitting substrate 6 through anti-reflection film 11 and repeating internal reflection between reflection film 12 which is located on opposing side surface 8 and semi-transmitting 23 which is located on one side of the side surface, as shown in Figure 6 (a) and (b).

Although exiting light was set at five with above embodiment examples, exiting light may be split into any number according to the requirement. Also, optical glass is mentioned as the transparent substrate, however, it may be such as transparent plastics with high light transmittance. As the dielectric material other than magnesium fluoride, silicon dioxide and zirconium dioxide of the embodiment example, it may be such as cerium fluoride, aluminum oxide, yttrium oxide, tantalum oxide, hafnium oxide and cerium oxide.

4. BRIEF EXPLANATION OF DRAWINGS

Figure 1 and Figure 2 are spectrum transmittance curve and schematic of the semi-transparent film, respectively, for explaining optical principle of the invention, Figure 3 is schematic drawing showing an embodiment example of the invention, Figure 4 is a graph showing optical thickness at light exiting points of said embodiment example, Figure 5 is a graph showing optical thickness at light exiting points when the optical thickness is increased, and Figure 6 is schematic showing another embodiment example of the invention.

G: transparent substrate, 7, 8: a pair of side surfaces, 9: incident light, 10: incident point, 11: anti-reflecting film, 10: reflective film, 23: semi-transmitting film

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Figure 1

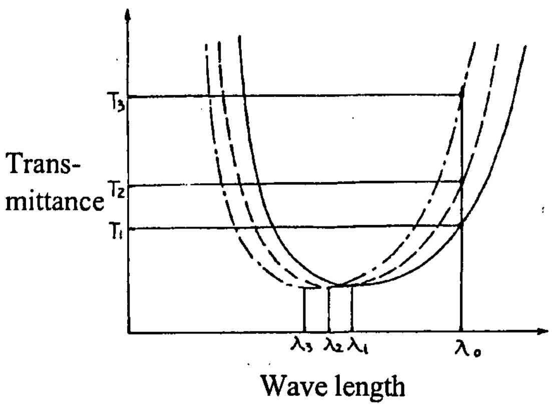

Figure 2

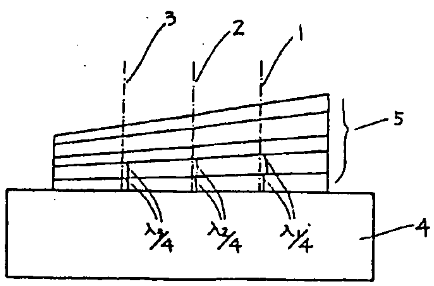

Figure 3

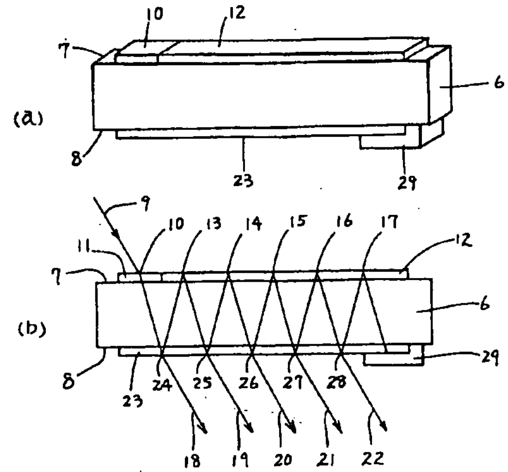

Figure 4

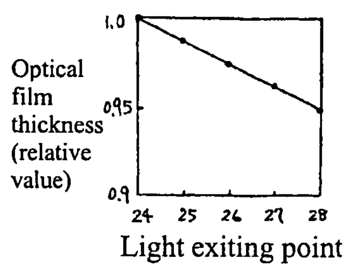

Figure 5

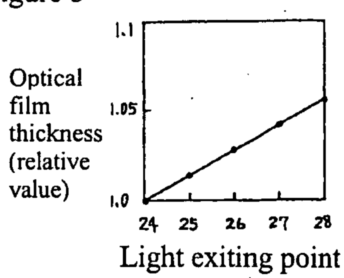

Figure 6